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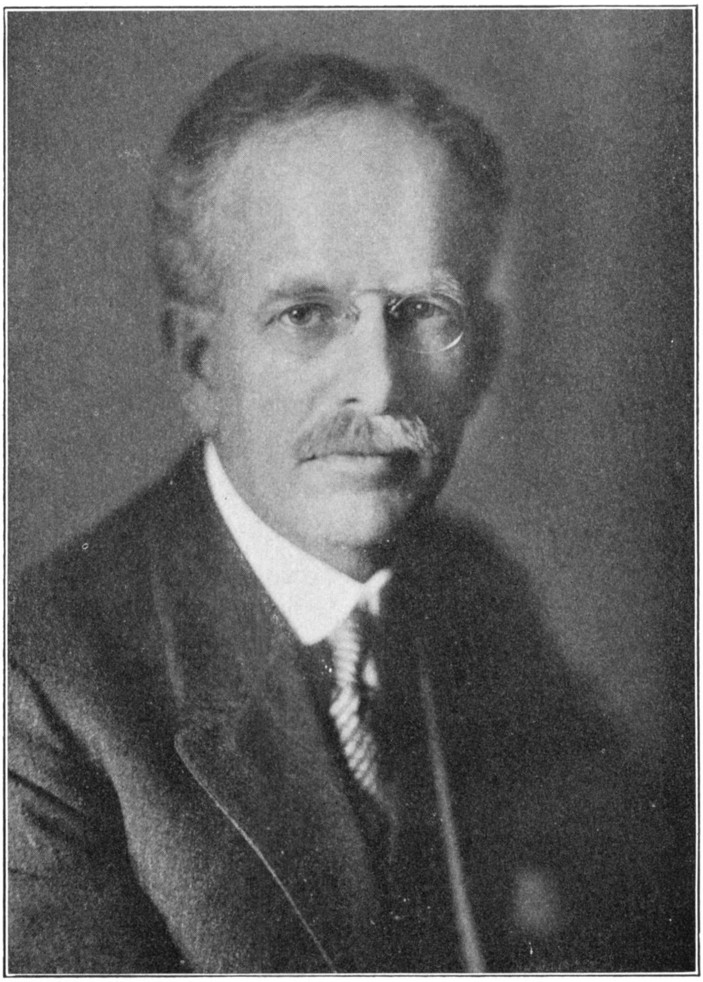


George Ellery Hale.

ADDRESS OF THE RETIRING PRESIDENT OF THE SOCIETY IN AWARDING THE BRUCE GOLD MEDAL TO DR. GEORGE ELLERY HALE.

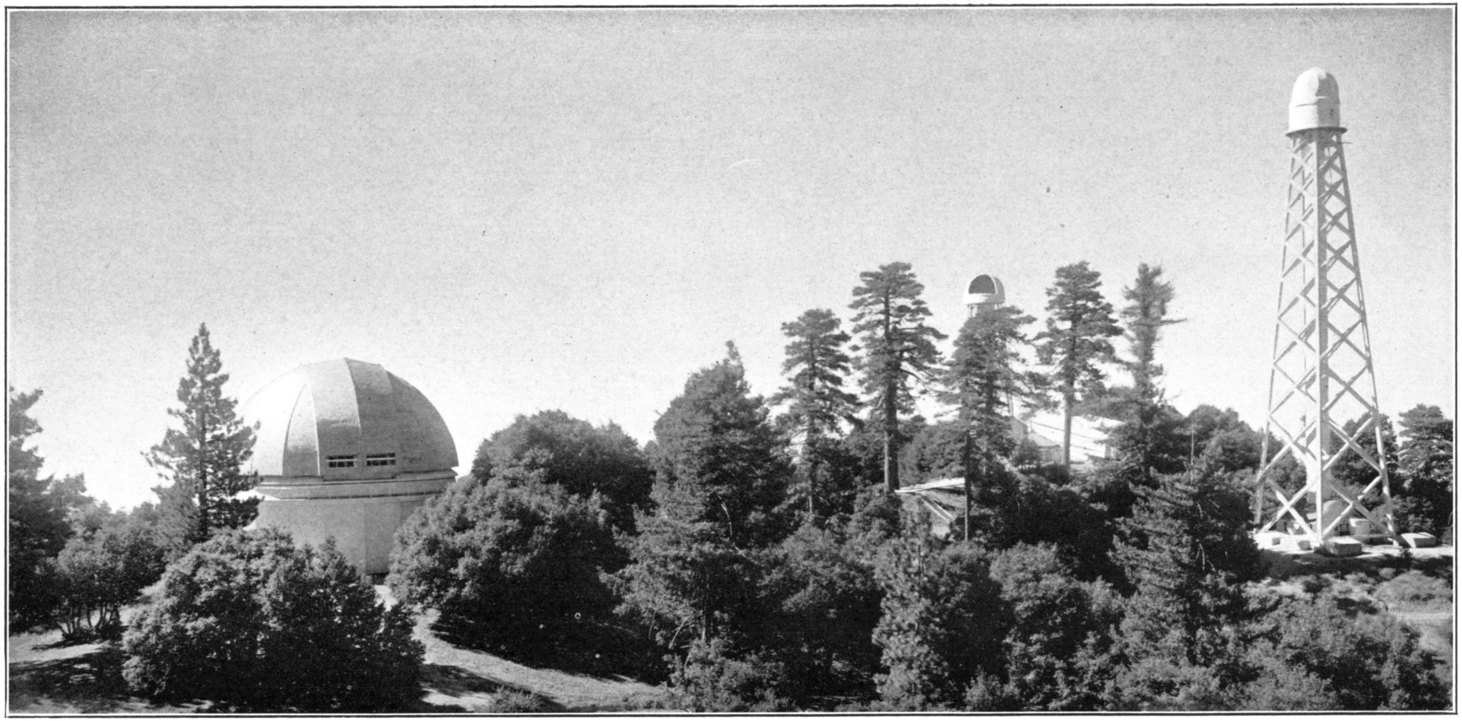
By Robert G. Aitken.

It is my privilege this evening as well as my duty to make the formal announcement of the award of the Bruce Gold Medal of our Society for the year 1916 to Dr. George Ellery Hale, the Director of the Mount Wilson Solar Observatory of the Carnegie Institution of Washington, and to state the grounds upon which the award has been made.

The Bruce Medal is international in character and is given for "distinguished services to astronomy" in any field. Among the twelve previous recipients of the award, we find four American, two English, and two German astronomers, and one representative each of Italy, France, Holland and Russia. In the list are men whose reputation rests entirely upon theoretical research; others whose preëminence is mainly due to observational work; some represent astronomy in Bessel's definition of the word, others are pioneers in what Langley called the "New Astronomy"; some have confined their attention chiefly to our solar system, others to the systems of the stars. Our present medalist is an American, a citizen of our own State, and a representative of the new astronomy, but he differs from all our earlier medalists in his chief subject of study, which has been and is the central body of our system, the Sun itself.

For fully twenty years Mr. Hale has been a professional astronomer, the organizer, builder and director of two of the great observatories of the world, but, by his own definition, he is still as truly an amateur as he was when he made his first astronomical observations in a room in his father's house in Chicago with instruments largely of his own design and construction. Hear his definition of the term!—"According to my view, the amateur is the man who works in astronomy because he cannot help it, because he would rather do such work than anything else in the world, and who therefore cares little for hampering traditions or for difficulties of any kind."

We should expect the man who wrote these words to be



View from the Balcony of the Dome of the 100-Inch Telescope.

characterized by an intense enthusiasm for research, and by the optimism necessary to carry him thru almost any discouragement, and this, indeed, is the fact. The fountain-head of these qualities must naturally lie in Mr. HALE's own nature, but he owes much to the fortunate environment of his early youth. His father, the late WILLIAM ELLERY HALE, to whom our medalist is, as he himself tells us, indebted beyond measure, fostered the boy's early love for natural science, was interested in his simple physical and chemical experiments, his observations of infusoria, his photographs of various objects with a microscope. He encouraged the boy to use tools and to build instruments of his own before buying better ones for him, and thus stimulated his enterprise, his self-reliance and his resourcefulness. In view of this early history it is less surprising to find our medalist as a boy of fifteen photographing the partial eclipse of the Sun in 1883, and to learn that even then he was passionately devoted to spectroscopy.

It was five years later, when he was a student at the Massachusetts Institute of Technology, that Mr. HALE designed a small brick building at his father's home at Kenwood to contain a ten-foot Rowland concave grating, with shop, laboratory and dark-room and thus began his active career as a builder of observatories and as an investigator of solar phenomena and of the problem of stellar evolution along the lines he has consistently followed in all his later work. Note that this first spectrograph was an instrument of *high dispersion* and that this first observatory made provision not only for a spectrograph, but also for a shop and a laboratory. Mr. HALE has from the beginning demanded powerful instruments, tho not necessarily expensive ones, and he has insisted upon shops and laboratories as indispensable adjuncts to an observatory.

In 1889, when he was but twenty-one years old, the principle of the spectroheliograph[1] occurred to him and with a simply constructed instrument he began his experiments at the Harvard College Observatory thru the kindness of Professor PICKERING. These early attempts were not successful, but three years later he had added a 12-inch refractor to the equipment of the Kenwood Observatory and in a photographic study of the spectrum of the solar chromosphere and prominences had observed the two brilliant lines due to calcium vapor in the Sun's atmosphere which are known as the H and K lines. Lying in the violet end of the visual spectrum, close to the limit of wave length to which the eye is sensitive, these lines had almost escaped notice in the visual studies of the Sun tho they had been seen by C. A. YOUNG. This short wavelength region of the spectrum, however, strongly affects the ordinary photographic plate, hence on the photographs the H and K lines are, as I have said, brilliant. Moreover they appear in the solar spectrum, superposed upon "broad dark bands which greatly diminish the brightness of the sky spectrum" and are therefore admirably adapted to the spectroheliograph.

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[1] The light of the Sun admitted into the narrow slit of an ordinary spectrograph and passed thru its train of lenses and prisms is spread out into a long band of color, crossed by lines representing various chemical elements. Such a "spectrum" can be recorded on a photographic plate. Suppose that immediately in front of this plate an opaque diaphram is placed with a narrow slit in it to correspond precisely to the position of one of the spectral lines. Obviously light from this line and from no other portion of the spectrum will be recorded on the plate. Now provide a mechanism to move the entire spectrograph (including the diaphram with the second slit), with respect to the solar image and the photographic plate. A complete picture of the Sun, in the light of this one spectral line, will be built up on the plate. The instrument is now a spectroheliograph.

The difficulties that had prevented earlier success with this instrument were now quickly surmounted, and early in February, 1892, Mr. HALE obtained fairly good images of the Sun in the light of the H and K spectral lines. A new and powerful instrument of fundamental importance in the study of solar phenomena was thus placed at the service of astronomy and Mr. HALE at once took a prominent place among the astronomers of the world.

It is probable that no one has ever made a discovery or invention of importance that had not been to some degree anticipated by others. It would be easy to cite numerous examples to support this statement. In the case of the spectroheliograph, the principle involved had been stated, essentially, by JANSSEN as early as 1869, an instrument had been designed by BRAUN, at Kalocsa, in 1872, but not built for lack of funds, and experiments with a spectroheliograph were actually carried out by LOHSE, at Potsdam, in 1880. They were unsuccessful, however, and LOHSE did not continue them. These facts in no wise detract from the merit of Mr. HALE's work, for he thot out the principle on which the instrument is based quite independently, and, what is of more importance, *he continued his experiments until he had achieved success.* The spectroheliograph is therefore justly regarded as his invention.

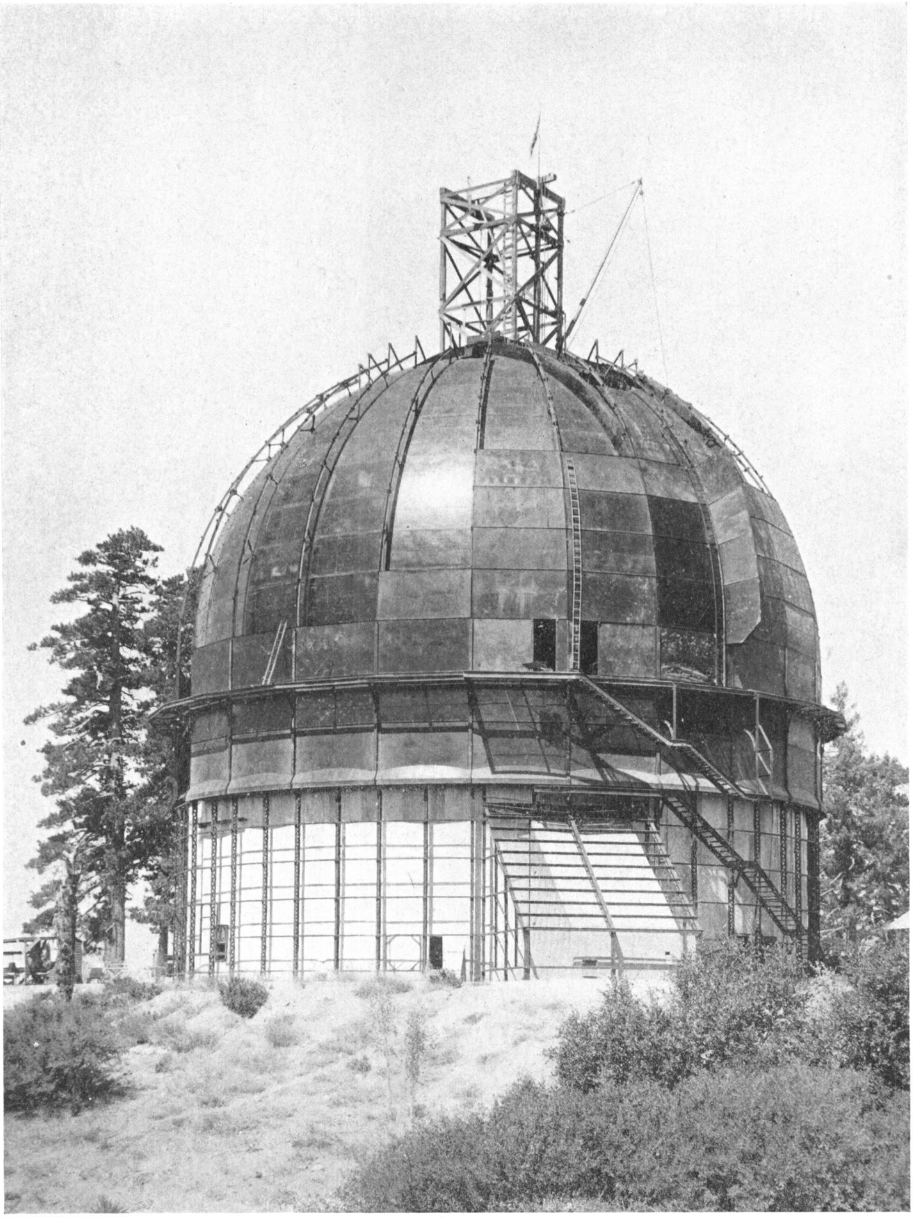
It is not my purpose to-night to dwell at length upon our medalist's multifarious activities as director first of the Yerkes, then of the Solar Observatory, as founder and editor of the *Astrophysical Journal*, as the man chiefly responsible for the organization of the International Union for Coöperation in Solar Research, but I do want to show you that all of these activities have been but the logical development, the evolution, if you please, of his original working program.

At the beginning of his work, Mr. HALE realized that the Sun is only a star, differing in no essential from thousands of the stars visible to the eye and to the telescope, except that it is placed near enuf to present to us a large disk instead of a point image, and thus to permit us to study its phenomena in detail. This is an obvious truth to us now, and was, indeed, no new idea a quarter century ago, but its implications and its opportunities had been so generally overlooked and neglected that Mr. HALE's revival of it held almost the novelty of a discovery. The Sun, then, as the "unique means of opening to us a knowledge of stellar development," held the central place in his scheme of research. That his conception of the problem of stellar evolution has grown and broadened as increasing knowledge and experience have brought an ever wider vision it is hardly needful to say, but it is apparent from his earliest writings and from the equipment of his observatory at Kenwood that he *began* his work with a firm grasp upon the conditions of the problem and a clearly outlined plan of attack upon it. The Sun was to furnish the key to decipher the mysteries hidden in stellar spectra, carefully chosen laboratory experiments were to guide in the interpretation of the observed solar phenomena, and the study of the stars and of the nebulæ in their relation to the Sun and to each other was to form the third of these converging lines of attack.

It is obvious that the full development of such a comprehensive program of work lies beyond the powers of any individual or even of any one institution, however well equipped. Every possible method of study and practically every form of telescope must be employed. Visual observations, with telescopes large and small, photographic observations, spectrographic observations, all have their particular functions. Moreover the student of stellar evolution must be alert to avail himself of every advance made in other fields of science, by the physicist, the chemist, and the engineer. He must constantly devise new instruments, new methods of attack, to apply these advances to his own problems. Finally, the Sun must be kept under continuous observation, not only from day to day, but from hour to hour, for prominences arise, reach their full development and vanish sometimes in the fraction of an hour; sunspots come and go on no regular schedule; faculæ and flocculi are as capricious in their changes as the clouds and air currents in our own atmosphere.

We find Mr. HALE, therefore, insisting upon the need of a large number of investigators "working, if possible, on some coöperative plan, at many stations widely separated in longitude." Intelligent coöperation is conditioned upon organization and upon convenient media of intercommunication. Recognition of these conditions led Mr. HALE to advocate as early as 1892, the foundation of an astrophysical journal, to undertake the editorial responsibility when it was established, and to take the initiative in the formation of the International Union for Coöperation in Solar Research, which held its first meeting in September, 1904. This admirable Union now includes practically every student of solar physics in the world and its organization is so skillfully planned that while it provides for thoro systematization and coöperation it leaves the initiative of every member full play, and, indeed, stimulates each one to original research.

It is but the further development of these ideas that has led Mr. HALE in more recent years to take such an active part in the work of the National Academy of Sciences, to emphasize the importance of National Academies as forums for the free interchange of thot by men engaged in different lines of research, and to establish, with his brother and sister, the *William Ellery Hale Lectures on Evolution,* for he regards "all natural phenomena as elements in a single problem," and believes, as Sir WILLIAM HUGGINS phrases it, that "through



Dome for 100-inch Telescope, September, 1915.

all the ages the Cosmos has advanced, and is still advancing, by a process of orderly evolution."

"The power of focussing simultaneously the wider view and the minute observation," says SCHUSTER, "is perhaps the most characteristic attribute of those who reach the highest eminence in any profession."

Mr. HALE possesses this power in a marked degree. The wider view has been emphasized in what I have been saying, but his personal research work has been characterized no less by minute and accurate observation. Without attempting to describe this work in detail, let me rapidly pass in review some of its more important features.

At Kenwood, the spectroheliograph was employed diligently until May, 1895, and a great variety of solar phenomena were recorded on the 3000 photographs secured. It was demonstrated that the spectroheliograph "provided a simple and accurate means of photographing the solar prominences in full sunlight," and that it revealed and recorded an entirely new class of phenomena, inaccessible to any other instrument. I refer to the enormous gas clouds in the Sun's atmosphere which Mr. HALE has named "flocculi"; for the photographs taken in the light of the H and K lines recorded the distribution of calcium vapor *above the Sun's disk* as well as in the prominences at its limb. The bright H and K lines are peculiarly adapted to spectroheliographic investigations, but it was apparent that with suitable instruments other spectral lines could be utilized and the distribution of other gases in the Sun's atmosphere studied. An instrument of higher dispersion was demanded for this, and to study the finer details of even the calcium flocculi an image of the Sun much larger than the 2-inch image formed by the 12-inch Kenwood refractor was needed.

Fortunately, in 1893, the opportunity to secure a refractor of the largest size presented itself, for by a combination of circumstances unnecessary to detail here, disks of glass of the highest quality, suitable for the construction of a 40-inch lens, were for sale. Mr. HALE interested President HARPER of the University of Chicago in the project, and the latter finally secured from Mr. C. T. YERKES of Chicago the funds for building the telescope and a suitable observatory. Naturally enuf, our medalist was called upon to build the new institution and to direct its work, and altho he realized the inevitable interruption to his personal researches involved, he recognized also the command to larger service for the common good and cheerfully shouldered the heavy responsibilities. The construction of the Yerkes Observatory was begun in 1895 and completed in 1897, and the new institution promptly took rank among the great observatories of the world, not only by reason of its powerful equipment, but even more because of the high quality of the work done by its staff. The wisdom of Mr. HALE's decision to base the scheme of work of the Yerkes Observatory "on a deliberate intention to realize the fullest possible advantages of the 40-inch refractor in the diverse researches for which it is peculiarly adapted" has been fully demonstrated.

Many of these researches are, in the nature of the case, not intimately related to each other or to the problem of stellar evolution, in which Mr. HALE's chief interest lies. The working program, however, provided for the study of this problem and it was Mr. HALE's hope that he could continue his spectroheliographic work without delay. Unfortunately, as is too often the case, there was no endowment fund for the new observatory, and the difficulty of finding funds for instruments supplementary to the great refractor and for the prosecution of the observatory work not only imposed heavy burdens upon our medalist, in his capacity as Director, but prevented the construction of a suitable spectroheliograph until 1898. The Rumford spectroheliograph then built was specially adapted to the 40-inch telescope, and the second slit was so designed that it could be used with any line in the solar spectrum and not merely with the bright H and K lines. With this instrument Mr. HALE succeeded, in May, 1903, in securing for the first time photographs of the Sun's image in light of the dark hydrogen lines, thus bringing the distribution of this gas in the solar atmosphere within the range of investigation. A far more striking achievement, one that savors of the miraculous, was the photographing of sections of the calcium flocculi at different heights above the photosphere of the Sun. This was accomplished by utilizing the "simple means first described by M. DESLANDRES."

"At the base of the flocculi," writes Mr. HALE, "the calcium vapor, just rising from the Sun's interior, is comparatively dense. As it passes upward thru the flocculi it reaches a region of much lower pressure, and during the ascent it might be expected to expand, and therefore to become less dense. Now we know from experiments in the laboratory that dense calcium vapor produces very broad spectral bands, and that, as the density of the vapor is decreased, these bands narrow down into fine, sharp lines. An examination of the solar spectrum will show that the H and K lines of calcium give evidence of the occurrence of this substance under widely different densities in the Sun. The broad dark bands, which for our convenience we designate H_1 and K_1, are due to the low-lying, dense calcium vapor. At their middle points (over flocculi) are seen two bright lines, which are much narrower and better defined. These lines, designated H_2 and K_2, are the ones ordinarily employed in photographing the flocculi with the spectroheliograph. Superposed upon these bright lines are still narrower dark lines, due to the absorption of cooler calcium vapor at higher elevations (H_3, K_3). It will be seen that the evidence of the existence of calcium vapor at various densities in the Sun is apparently complete, and that we may here find a way of photographing the vapor at low levels without admitting to the photographic plate any light that comes from the rarer vapors at higher levels. It is simply necessary to set the second slit of the spectroheliograph near the edge of the broad H_1 or K_1 bands in order to obtain a picture showing only that vapor which is dense enuf to produce a band of width sufficient to reach this position of the slit. No light from the rarer vapors above can enter the second slit under these circumstances, since they are incapable of producing a band of the necessary width."[1]

The great sun-spot of October, 1903, offered the opportunity for testing the new method and the results were completely successful. It is a temptation to describe the differences in the structure of the hydrogen and calcium flocculi and the variations in the latter with their level in the solar atmosphere, and to discuss their bearings upon our theories of the forces at work in the Sun. Time, however, is lacking and it must suffice to say that Mr. HALE has developed these points in various papers reporting the progress of his investigations.

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[1] *The Study of Stellar Evolution*, p. 90.

For the same reason we must pass over the other work done at the Yerkes Observatory, with merely the briefest reference to the research on the Spectra of Stars of SECCHI's Fourth Type—the so-called carbon stars--which was undertaken in January, 1898, with the assistance of ELLERMAN and PARKHURST, and which affords an admirable illustration of the "combined attack" method in studying astronomical problems. "In conjunction with this investigation," says Mr. HALE, "photographs have been made of the spectra of a number of stars of other types, researches on the condition of carbon in the solar chromosphere and on the widened lines in sun-spots have been set on foot, and considerable work on the spectrum of carbon and other substances has been done in the laboratory."

Exceedingly valuable work in solar research has been, and is being done with the Rumford spectroheliograph, but Mr. HALE recognized the promising opportunity that remained to apply instruments of higher dispersion "to the investigation of sun-spots, the chromosphere, and other details of a large solar image." Such instruments are too long to be attached to a moving telescope and "it became necessary to develop a suitable form of fixed telescope," which could be made to bring a large scale image of the Sun to a focus at the slit of a powerful spectroscope or spectroheliograph mounted on fixed supports. A beginning in this direction was made by the construction of the Snow horizontal telescope at the Yerkes Observatory. "It consists of a coelostat, with a plane mirror 30 inches in diameter, rotated by clock work at such a rate as to keep the beam of sunlight, reflected from its silvered (front) surface, in a fixed position on a second plane mirror standing above and south of it. From this mirror the beam is reflected nearly horizontally to a point 100 feet north, where it falls on a 24-inch concave mirror of 60-feet focal length, which forms a solar image about six and one-half inches in diameter on the slit of a spectroscope or spectroheliograph."

Before work with this telescope had passed the experimental stage an appropriation was secured from the newly established Carnegie Institution of Washington to take it (in 1904) to Mount Wilson in California, where preliminary tests had shown that the conditions were unusually favorable for solar observation. The results secured were entirely satisfactory and doubtless formed a large factor in the decision of the Carnegie Institution to establish a solar observatory on this site. To our medalist was again entrusted the responsibility of planning, and directing a great observatory—an observatory this time, whose prime object it is "to apply new instruments and methods of research in a study of the physical elements of the problem of stellar evolution," with special attention to solar physics.

Experiments in photographing the Sun from a station in a tall pine tree on Mount Wilson convinced Mr. HALE that it would be a great advantage to mount a coelostat high enuf to avoid the disturbed image due to ground radiations. Accordingly a telescope of entirely novel type, the "tower telescope," was designed. A simple "windmill tower" was erected, supporting a platform, about 65 feet above the ground, on which the coelostat and second mirror were so mounted as to send the beam of sunlight vertically downward thru a 60-foot-focus lens which formed an image of the Sun just above the ground. Here it fell upon the slit of a spectroscope or spectroheliograph which was placed at the bottom of a "well" 30 feet deep, where the temperature remained almost constant and where there was no vibration. The success achieved with the 60-foot tower telescope has more recently led to the construction of another, with a tower 150 feet high, and well 75 feet deep, which forms a solar image nearly 17 inches in diameter.

Another powerful instrument at Mount Wilson is the 60-inch reflecting telescope, the mirror for which had been partly completed at the Yerkes Observatory. It is not used for solar work, but for observations on stars and nebulæ, designed "to throw light on the past and future condition of the Sun." This magnificent instrument is the most powerful one of its type in actual use, but one even larger, with a mirror 100 inches in diameter, is nearly completed, and may be in operation by 1917.

The Snow telescope, the two tower telescopes, and the two giant reflectors, with their accessories on Mount Wilson, and the splendid laboratories and shops at Pasadena, constitute a well-nigh ideal equipment for that combined attack upon the problem of stellar evolution which has from the first been Mr. HALE's ambition. That marvelous advances in our knowledge will result is attested by the work already accomplished, partial accounts of which are published in the four volumes of "Contributions from the Mount Wilson Solar Observatory." Here we find spectrographic studies of the Sun's disk at the center and near the limb; of sun-spots, prominences, and the "reversing layer"; of stars, nebulæ, and the Milky Way; of iron, titanium and other elements made in the laboratory under varying conditions of temperature and pressure and under the influence of a magnetic field; also spectroheliographic studies of prominences, sun-spots and flocculi, and scores of other researches—all related to some phase of the one great problem.

It was in 1908 that a staining method devised by WALLACE for making photographic plates sensitive to red light, enabled Mr. HALE to use the $H\alpha$ line of hydrogen in his spectroheliographic studies. It had been practically demonstrated at the Yerkes Observatory as early as 1903 that the hydrogen vapor which produces the $H\beta$, $H\gamma$ and $H\delta$ lines in the spectrum of the prominences, and which forms the hydrogen flocculi lies at higher levels in the Sun's atmosphere than does the calcium vapor responsible for the H_2 and K_2 lines. Indeed, even then Mr. HALE stated that the strongest hydrogen flocculi were probably "prominences" seen in projection upon the Sun's disk. Evidence was also found which favored the belief that the $H\alpha$ line in the red end of the spectrum came from hydrogen at still higher levels. The spectroheliograms made with this line early in 1908 raised this conclusion from an assumption to a demonstrable fact, confirmed the earlier hypothesis that many of the flocculi were prominences in projection on the disk,[1] and, further, clearly revealed a "vortex" structure in the atmosphere above the sun-spots.

It is this vortex structure that has chiefly engaged Mr.

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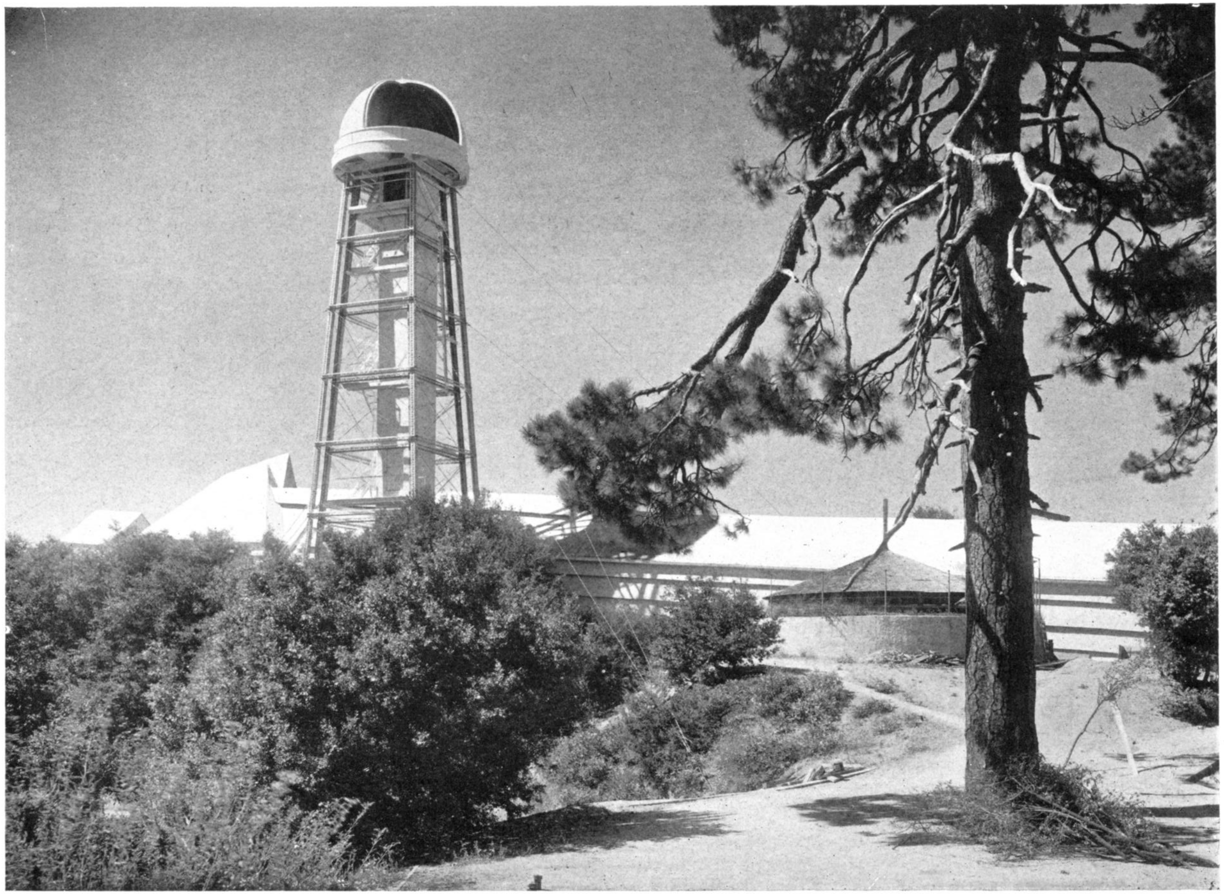
[1] Recent photographs with the new 13-foot spectroheliograph have proved this more conclusively, and EVERSHED and RICCO have reached the same conclusion from their researches.



Sixty-foot Tower Telescope, Showing Outer Tower, Dome and Vertical Tube (Recently Added).

HALE's attention in the researches his health has permitted in the past seven years—and the remarkable discoveries he has made and the conclusions to which he has been led form one of the brilliant chapters in the history of solar research.

The theory that sun-spots are in some manner the manifestations of cyclones or vortices in the Sun's atmosphere is, of course, no new one. It is the *proof* that is new. New, too, is the development from these observations that sun-spots are the centers of magnetic fields. This was suggested by Mr. HALE in his first paper on "Solar Vortices," which also pointed out the methods to use in testing the hypothesis. Here, again, he shows his alertness to utilize every advance made by workers in other fields, for it was by showing that the spectra of sun-spots exhibit the doubling and tripling of lines and the polarization phenomena which ZEEMAN in his laboratory researches had proved to be the distinguishing characteristics of the spectrum of a light source placed in a magnetic field that Mr. HALE was able to confirm his hyphothesis. To pass from this to the attempt to detect the presence of a general magnetic field in the Sun was to him the natural next step. Even to men so skilled in experimentation, so resourceful in devising new methods and so well equipped with powerful apparatus as are our medalist and his colleagues, this research presents extraordinary difficulties. Nevertheless, success is crowning their efforts, and it has been proven that the Sun, like the Earth, is a great magnet. The latest results even give a value for the inclination of the Sun's magnetic axis to the axis of rotation and indicate that the former axis revolves about the latter in a very short period.

Mr. HALE subscribes to HERSCHEL's dictum that "to draw not only certain conclusions, but also conjectural views" from observations is "the very end for which only observations ought to be made." He is very careful, however, to discriminate between apparently certain conclusions and purely conjectural views in which, as he says, "we must be constantly on our guard against specious resemblances." Always, moreover, he takes pains to point out the lines and methods of research that provide critical tests for his hypotheses, and, like every true man of science, he stands ready to abandon even his most cherished theories when new evidence turns against them.

It has been my object to show that "continuity of purpose and a definite scheme of research, bringing a variety of methods to bear upon a common end," have been the distinguishing characteristics of all of our medalist's work. I need hardly apologize for omitting even the mention of many of his important contributions to knowledge, for as long ago as 1904, in his address in awarding Mr. HALE the Gold Medal of the Royal Astronomical Society, Professor TURNER said that "to attempt to follow the activities of such a man during a dozen years in the space allotted to this address would be merely bewildering." What would it be now after eleven additional years of activity! It is enuf if, in my incomplete and very imperfect sketch, I have shown that our medalist has indeed rendered "distinguished services to astronomy."

He would not have me close, however, without definitely pointing out that he has not been the only successful worker in solar research in the past quarter century. He would, I am sure, wish me to remind you that Mr. EVERSHED, in England, began work with the spectroheliograph within a few months, and M. DESLANDRES, in France, about a year after the time when his own first success was achieved, and that they and many others have been most active in extending our knowledge of the complicated phenomena of the Sun. Nor would he have me fail to remind you of the value of these researches to him in his own work, and of the great assistance rendered by his colleagues (especially by ELLERMAN, who was with him at the Kenwood as well as the Yerkes Observatory, and who was the first to go with him to Mount Wilson), for he has ever been the first to recognize the merits of any research by others and to acknowledge his own indebtedness to others. In his letter accepting the award of the Bruce Medal he writes that "credit for the work of both the Mount Wilson and the Yerkes Observatories is due in very large degree to my present and former colleagues," and in a later personal letter he reiterates this statement. In the latter he also voices his hope never to leave the work at Mount Wilson, and says "my one desire is for an opportunity to push forward my investigations with effective instrumental means."

Mr. Hale, in consequence of conditions brought about by the European war, the Bruce Gold Medal ordered for you from the Paris Mint has not yet reached us. I therefore hand you this bronze replica in token of the award, the highest honor within the gift of our Society.

We all join in the earnest hope that long years of health and strength may be granted you to improve the splendid opportunity which lies before you and which you yourself have done so much to create.